Physical Observations during a Total Solar Eclipse

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Reprinted from the Calcutta Review, September, 1922

CALCUTTA UNIVERSITY PRESS

1922

BCU 2772

GS2815

PHYSICAL OBSERVATIONS DURING A TOTAL SOLAR ECLIPSE

The occurrence of a total solar eclipse is a phenomenon of unusual interest to the astronomer. It affords him an opportunity of studying physical conditions in the sun on a scale which is not otherwise available. The memory of the last eclipse which we had, may be still fresh in the public mind. It occurred on the 29th May, 1919, and is celebrated as the occasion, on which Prof. Einstein's famous predictions about the deflection of light rays by the gravitation field of the sun was verified. Another total eclipse is coming shortly —September 21st, 1922—and this time the track of the moon's shadow will sweep across the Indian Ocean from the Maldive Islands to the West Coast of Australia passing close to Java. The chief item in the programme is to obtain fresh support for Einstein's theory by securing photographs of stars during the moments of totality.

But the interest and importance of a total solar eclipse to the astronomer is older than Einstein by at least six decades. It began from the year 1859 when **Kirchoff** in Germany discovered spectrum analysis and placed in the hands of scientists a method which enabled them to study the chemical composition of not only terrestrial minerals, but also of such distant and unapproachable bodies as the sun and the stars.

To the unaided eye, the sun appears as an intensely bright circular disc. But about this disc (which is known in the astronomer's language as the **photo-sphere**) there is an atmosphere (known to the astronomer as the **chromosphere**) of glowing gases. We cannot see this atmosphere in broad daylight because it is lost in the general glare of the sun ; for the same reason the stars and the planets are not visible in daytime. If somehow the bright disc could be veiled, the atmosphere would be visible to the naked eye.

Fortunately for us, this is done by the moon during a total solar eclipse. The moon comes just between the earth and the sun and sends out a conical shadow with a maximum diameter of 168 miles at the point where it meets the earth. The shadow sweeps across the surface of the earth with a minimum velocity of 1,000 miles per hour (almost the same as that of a cannon ball). To all persons lying within the track of the shadow, the disc of the sun becomes invisible for the maximum period of nine minutes (equal to $\frac{168}{1000}$ hours). This is known as the period of totality. It is well to bear in mind that 9 minutes is the greatest possible duration of totality. The actual period of totality may be anything from 9 minutes to nothing.

In ancient times when people had not yet learnt to calculate the date and time of a total solar eclipse in advance, and await the phenomena with stoic indifference, such occurrences often gave rise to much terror and superstition. This is scarcely to be wondered at, because people lying within the zone of totality suddenly find themselves plunged from bright sunshine into the deepest gloom. The sky-light is so much reduced that planets and big stars and sometimes stars of the third or the fourth magnitude become visible. The transition is extremely sudden and abrupt. (It is said that once in ancient times, two contending armies were caught up in a total solar eclipse and were so much smitten with fear that they broke action and fled away in panic.) In a few minutes, however, the gloom passes away, giving place to full sunshine.

Let us see how the astronomers use these precious few minutes. They are precious, not only on account of the extreme shortness of duration of totality, but also because of their rarity. 13 total eclipses occur in a period of 18 years 10⅓ days (usually known as the Chaldean Saros after the nation which discovered this period), yet only a minute fraction of the earth's surface is fortunate or unfortunate to receive them. It is calculated that if a total solar eclipse happens to occur once in a certain place, the probable time that will elapse, before it occurs there again, is 360 years. "Nine minutes once in 360 years" has certainly a claim to be called precious.

Before the discovery of spectroscopy, the programme was limited to the observation of the gradual progress of the moon across the sun's disc with the aid of a telescope (with the usual darkening devices). Four stages are distinguished. The moon just touches the disc of the sun **(first contact)**, then gradually creeps along the disc making the intersected crescent thinner and thinner ; this occupies about an hour. The cusp is gradually reduced to a line, and then vanishes abruptly. At this point, the moon just touches the disc on its inner side (**second contact**), and totality begins. The photo-sphere is completely veiled.

The maximum possible excess of the moon's disc over that of the sun is only 79″—so that within at most 4 minutes of second contact, the moon creeps along and touches the sun's disc at the point opposite to that of the second contact **(third contact)**, totality is now at an end. The moon continues to creep on, the thin crescent gradually waxes, till the two discs separate **(4th contact)**. Eclipse is now at an end. For the astronomer, the period between the 2nd and 3rd contacts is most valuable.

While carefully watching the progress of the eclipse through the telescope, it was observed by Airy and many other observers, that at the moment of second contact, when the cusp of the sun just disappeared, red columnar flames shot out across the field of vision. To these the name '**Protuberances**' or **Prominences** were given, but opinions were divided about **their physical** nature. Some said that they were parts of the moon, others said they were illusions, while a few held that they were huge jets of gas projected from the surface of the sun forming part of a general solar atmosphere.

The controversy was settled by the Italian Padre Sechhi, and by Warren de la Rue taking a series of photographs of the solar atmosphere during a total eclipse in 1860. These photographs established beyond doubt that the **prominences** formed part of the sun, and consisted of luminous masses emitting rays of great actinic power.

But the most imposing sight about the sun during the moments of totality is a magnificent luminous halo extending to great distances in free space. Very often, this luminous halo is topped with bright pointed arches, which give it the appearance of a crown. Hence the name "**Corona**" has been given to it. It seems to have been observed at a very early time, for it was known to Kepler and Galileo. Since 1851, innumerable photographs of the corona have been secured, showing great variety of form, and extension.

Near about the solar disc, the coronal light becomes more intense, and passes into a brilliant red ring of light, to which the name '**chromosphere**' has been given. The observation of the corona, the chromosphere, and the prominences formed the chief items in the older eclipse programmes. But laterly, methods were devised by means of which, the chromosphere and the prominences can be observed in full daylight.

Application of the spectroscope to solar physics.—In 1859, Kirchoff announced to the world the news of his discovery of spectrum analysis. The effect of this discovery may be likened to the annexation of a fresh world of knowledge to the domain of human intellect. Newton had shown about 1680 that solar light consists of the seven colours of the rainbow. In 1813, Fraunhofer, then a humble spectacle-maker of Munich, surprised the scientific world by his announcement that the solar spectrum was not continuous, but was intersected in places by fine dark lines. These dark lines remained a perfect mystery for about forty years in spite of many efforts by scientific men to explain them (or rather explain them away). But Fraunhofer recognised that deep meaning might be hidden in them, measured and catalogued them for future use.

Continuous spectrum and Line spectrum.

The explanation, which we owe to Kirchoff, is as follows. A piece of white-hot iron or the glowing carbons of an arc emits a continuous spectrum. A gas on the other hand, emits a line spectrum. If a flame is sprinkled with the salt of some metal, it is well known that it is tinged with definite colours. Thus sodium salts tinges the flame yellow, strontium makes it red, copper makes it peacock-green. On spectroscopic examination, these colours are resolved into a number of fine bright lines; which are characteristic of the element present in the flame. Thus sodium emits two lines in the yellow, copper emits a number of lines in the blue, and every element has its own array of lines. It was observed, by Fraunhofer himself, that the yellow lines of sodium were identical with the dark lines D_1 and D_2 of the solar spectrum. Later observations showed that most of the Fraunhofer lines could be identified with the lines of elements known on the earth.

With the aid of new ideas on emission and absorption of radiant energy, these facts were woven by Kirchoff into a consistent theory of the Fraunhofer spectrum. This explanation is now a matter of common knowledge. The continuous spectrum comes from the highly condensed central nucleus (photosphere) of the sun, which emits like a solid body (this does not mean that the nucleus is solid—the more probable theory is that the nucleus consists of highly compressed gas). The light from the photosphere has to pass through a surrounding thinner atmosphere in which all terrestrial elements *e. g* iron, sodium, calcium, etc., are present in the state of vapour. These vapours act like filters, and rob the continuous spectrum of the light which they themselves can emit. Thus sodium vapour in the solar atmosphere absorbs the D_1 and D_2 light from the photospheric

Fraunhofer spectrum and reversal of lines.

spectrum; they also emit the same light, but the intensity is very much smaller owing to the lower temperature of the atmosphere. The transmitted light which is made up of what remains of the photospheric light after absorption plus the light emitted by the vapours themselves is less intense than the original beam from the photosphere. Hence the beam appears dark in comparison.

It is well to bear in mind that the darkness is only comparative. In reality, the dark lines are as intense as the lines of the flame or sometimes of the arc, as is proved from the fact, that with sufficient exposure, all parts of the photographic plate become dark. It naturally follows that if the photospheric light could be somehow cut off, and the solar atmosphere isolated, its spectrum would be found to consist of bright lines like that of a gas. *In place of each dark Fraunhofer line, we shall get a bright line, in other words, the spectrum of the solar atmosphere would be a complete reversal of the Fraunhofer spectrum.* This opportunity is afforded only during the moments of a total solar eclipse. It may be supposed that if we hold a sufficiently large disc before the telescope, so as to cover the photosphere completely, our object would be achieved. But this is not so. Besides getting light direct from the sun, we get light from all parts of the sky, which is simply sunlight scattered by the dust and air molecules of the atmosphere. The intensity of the sky-light is sufficient to mask the solar atmosphere completely. The bigger the disc the less intense will be the sky-light, but **it actually requires a disc as big as that of the moon to make the solar atmosphere at all visible.**

The importance of a total solar eclipse will now be quite evident, but the reader must not underestimate the difficulties. It is very difficult to catch the exact moment of totality. Then the moon shoots across the surface of the sun with tremendous velocity, covering 270 kms. of the solar surface per sec. **Hence if any spectroscopic study is to be made about the 100 kms. just next to the solar disc, it must be**

started and finished within $\frac{1}{3}$ of a second beginning from the instant of second contact.

At first astronomers concentrated their attention on the observations of the spectra of red prominences, which extend to great heights, and can be observed for a considerable length of time. Observations of the spectra of red prominences stood in the forefront of the expeditions to observe the total solar eclipse of 1868, which passed over India. Parties were organised by the French, English, and American astronomers, but success was reserved for the Frenchman **Jansen**. But before relating the account of this success, we must mention the appearance on the scene of a very remarkable personality—the late **Sir Norman Lockyer**—one of the greatest figures in solar physics, and one who was destined to influence the course of astrophysics for the next fifty years. Lockyer was, at this time, earning a small pittance as a humble clerk in the Admiralty. He was a man without regular University education, but what he lacked in routine education was made up by his energy ("tumultuous" is the adjective with which his biographer describes it) insight, and great powers of organisation, and above all his love of the subject. Lockyer hit upon the bold idea of photographing the spectrum of the red prominences in broad daylight, and with his own scanty means, set about the work in great earnest.

Spectra of Prominences.

Lockyer recognised that the chief difficulty in his way was the sky-light, which, as explained before, completely masks all light from the solar atmosphere. The sky-light is simply solar light scattered by the terrestrial atmosphere, and its spectrum is the same as that of the sun. So a method had to be found by means of which the sky-light could be weakened, while the intensity of the line spectrum from the prominences would remain unaffected.

The way in which this was effected occurred independently and simultaneously to Lockyer and Jansen, under different circumstances. It is this—suppose we have a spectroscope consisting of simple prism, and observe with it the continuous spectrum of sky-light, and line spectrum of say a Vacuum tube. Suppose, the total length of the continuous spectrum between C and F is 3 cm. Now let us add another prism having the same dispersion. The length of the spectrum (C—F) will now be 6 cm. the intensity of the continuous spectrum will therefore be halved. The intensity of the individual lines of the line spectrum would however remain unaltered, for they are monochromatic. If we have *n* prisms, then neglecting the weakening in intensity due to absorption and reflection, the intensity of the continuous spectrum would be reduced *n*-times, that of the line spectrum would remain unchanged.

The perfection of the experimental method was, however, not the only difficulty which Lockyer had to encounter. The prominences were shown by Sechhi to be isolated masses, scattered irregularly over the solar disc. Nobody knew at which part of the sun's disc one had to look for them. So we need not wonder why it was after three years' labour that the difficulties of the work were overcome. In October, 1868, Lockyer succeeded in photographing the spectrum of the protuberances in broad daylight.

Indian Eclipse Expeditions of 1868.

But Lockyer had to share the honours jointly with Jansen. While engaged in the eclipse observations at Guntoor, it occurred to Jansen that the spectrum of the protuberances might be photographed in daylight, and the same method which was being perfected by Lockyer occurred to him independently. He was, however, more fortunate than Lockyer, for from his observations during the total eclipse, he had come to know the exact spot where he had to look for the prominences. Not only that, his observations showed that the most prominent line in the prominence spectrum was the C-line of hydrogen, not the sodium D-line, which had monopolised all the attention before this time. Jansen confirmed this on the next day by actual observation, and was so elated with success that he telegraphed to Paris "We have now total solar eclipse for the whole day." The observation was continued up to the 4th September; and then posted to France.

Jansen's observations were made at Guntoor in India. The news of his discovery reached Paris on the 26th October when it was read by Faye before the Paris Academy. By a mere accident, the news of Lockyer's discovery reached the Academy the same day. To commemorate this event, the French Government struck a medal containing, on one side, the effigies of the two astronomers, on the other side, the Sungod carried away as a captive in a chariot drawn by four horses and containing the inscription " Analyse des Protuberances Solaires, 18 Aout, 1868.

Shortly after Lockyer's discovery, Huggins showed that by placing the slit tangentially to the solar disc, and opening it rather wide on the side of the chromosphere, that the whole protuberances could be observed. In 1892, **Hale** in America, **Deslandres** in France, and **Evershed** in India discovered an instrument called the **spectroheliograph**, by means of which it is possible to photograph the prominences in broad daylight. Photographing the prominences is now a regular routine work at Kodaikanal, Mount Wilson, and many other solar observatories. **Mr. Evershed** of the Kodaikanal observatory has observed a huge number of prominences and published them in a book form.

In many respects, Lockyer went further than his contemporaries. He confirmed Sechhi's view that the protuberances were elevations from a continuous atmosphere surrounding the sun, for which he, in conjunction with his friend Frankland, suggested the name **chromosphere. (sea of colours)** He showed that the D-line of the protuberance spectrum was not identical with the sodium lines, but its wave-length was considerably shorter (5876 against 5890-96 of D_1 and D_2) He called it D_3. It is not represented in the Fraunhofer spectrum, and was ascribed by Lockyer to a new lement still undiscovered on the earth. He christened this hypothetical element Helium, after Helios, the Greek name for the sun-god." Thirty years later, Helium was discovered by Ramsay in the Norwegian mineral Clevite.

Discovery of Helium in the Sun.

But the proof that the spectrum of the chromosphere would be the reversal of the Fraunhofer spectrum was not yet forthcoming. Instead of showing thousands of bright lines the spectrum of protuberances showed only a few bright lines (11 in all).[1] This discrepancy cleared itself in 1870.

Prof. Young of Princeton, was observing a total solar eclipse on Mt. Sherman. With the slit of his spectroscope tangential to the sun's limb, and perpendicular to the moon's advance, he was awaiting the moments of the second contact. " The thin solar crescent narrowed second by second, then "all at once, as suddenly as a bursting rocket shoots out its stars, the ordinary Fraunhofer lines previously visible were replaced by a serried array of bright lines on a dark background. This seemed a complete reversal of the familiar absorption-rays and the impression was also conveyed to Mr. Pye, a member of the same party." (The description is taken from Mrs. Clerke's Problems in Astrophysics).

The spectrum of the chromosphere.

This flash-like reversal had been looked for, and been confirmed. But a photographic record could be taken only 26 years later in 1896, by Mr. Shackleton at Novaya Zembya, during the Arctic Eclipse of 9th August, 1896.

In this expedition, a prismatic camera was used. It is a simple form of spectrograph, without slit and collimating lens. The slit is unnecessary, because at the moment of totality, the source of light is the thin crescent-like part of the solar chromosphere intercepted by the moon's disc. By means of the prism, this thin crescent shaped source of light is drawn out into a series of monochromatic images. Some of these arcs are long, others are short. The employment of this apparatus in eclipse work is mainly due to the initiative of Lockyer. It is generally known as the **Flash spectrum**, on account of the flash-like rapidity with which it appears and disappears.

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[1] In 1871, there was a total solar eclipse passing over India. Lockyer observed the spectra of prominences, and showed that it gives hundreds of lines.

Flash spectrum.

A magnificent opportunity presented itself in the year 1898, Jan. 22, when there was a total solar eclipse passing over India. Photographs of the flash spectrum and the corona were secured by Lockyer at Viziadrug in the Bombay Presidency, by Evershed at Talni, and by Naegamvela.

Indian Eclipse Expeditions of 1898.

The full story of these expeditions is told by Lockyer himself in the pages of the Philosophical Transaction, Vol. 197, 1901, and by Evershed in the same journal. At Viziadrug totality began at 12 *h.* 45 *m.* 53 *s.* and lasted for 127 seconds. Many photographs of the flash spectrum were secured, one set with a six inch prismatic camera, the other set with a nine inch camera. Photographs of the corona were secured : and its spectrum was also observed, though not very satisfactorily.

The eclipse of 1898 was the first occasion in which, there was no mishap, the programme went like clockwork. "The ice being once broken," all the subsequent total eclipses have been fully exploited by astronomers, English, American, Dutch, French and German. But anything like an account of these expeditions is quite out of the question.

All eclipse expeditions did not prove successful Sometimes at the psychological moment, clouds gather in the field of view spoiling all labour and money. Sometimes, the occurrence of the eclipse causes disagreeable activity among the surrounding populace One eclipse expedition to India is said to have been completely spoilt by some jungly tribes setting

Between 1871 and 1896, Lockyer had planned several expeditions, but owing to unforeseen accidents, all of them came to naught. The inclusion of eclipse observation in the Arctic expedition of Shackleton was due to Lockyer's initiative, but he was prevented from being personally present.

The prismatic camera was first used in 1871 fire to forests at the commencement of the eclipse. In 1914, owing to the outbreak of the Great War, the British expedition to Crimēa in south Russia had to beat a precipitate retreat, abandoning all the instruments, which were never recovered.

Up to 1919, the programme had not much varied. The items were —

(1) Precise observations of the times of four contacts; these observations determine with great accuracy the relative positions of the sun and the moon at the moment, and serve as useful data in the theory of lunar motion.

(2) The search for a possible intramercurial planet.

Physical obervations during a total solar eclipse.

Mercury is the innermost planet of the solar system, but accurate observation of Mercury shows that it does not strictly follow the Newtonian law of Gravitation; the apse-line has a progressive motion of 540″ per century, of which 43″ cannot be accounted for by the law of gravitation. The observed perturbation was formerly supposed to be due to the presence of a hypothetical planet between the sun and mercury, and the name "Vulcan" was coined for it. If such a planet really exists, it may become visible during the moments of totality.

But "Vulcan" has never turned up. The Perihelion motion of Mercury is now explained completely by Einstein's theory of Generalized Relativity. So it seems doubtful if Vulcan at all exists.

(3) Photographic records of the form of the "Corona" and photometric measurement of the intensity of coronal light.

The Corona is an essentially "Eclipse Phenomena" as all attempts to photograph it during daytime have failed. At outer regions, it is only half as intense as the full moon.

(4) Certain meteorological observations, such as effects on the thermometer, the barometer, and the magnetic elements of the earth. (L. Bauer of the Carnegie Trust has specialised in this line.)

(5) Examination both visual and photographic of the spectra of the flash, the corona, and the prominences.

This item is by far the most important in an eclipse expedition.

Since 1919, another item has been added to the programme:—The verification of Einstein's prediction that rays of light would be deflected on passing close to the disc of the sun. The predicted deflection is 1·74 $\frac{r}{R}$ seconds of arc where "r" is the semi-diameter of the sun, R is the angular distance of the star from the centre of the sun.

Photographs of the field of stars about the sun are secured during the moments of totality. These photographs are compared with another set secured either before or after this event, when the sun is not in this region of the sky. The comparison reveals any displacement which star might have suffered owing to its rays having to pass close to the sun's disc during the moments of totality.

It is hardly necessary to add that the results of the British expedition of 1919 confirmed Einstein's predictions in a most brilliant manner. The coming eclipse is also said to present a very favourable opportunity, as the field about the sun contains a number of sufficiently bright stars. A method proposed by Prof. Lindemann of Oxford of securing photographs of stars in daytime in infra-red light was tried by Evershed, at Kodaikanal but did not yield any positive result.

Results of the spectroscopic examinations.

Interest in these observations has somewhat flagged of late owing to the sensational nature of Einstein's prediction, but this attitude is scarcely to be justified. The results which have accrued from these observations are highly interesting and present a number of problems still awaiting solution.

We have already remarked that Rowland measured about 20,000 dark lines in the solar spectrum in the region between 3000 A.U. to 7800 A.U. A number of these are due to absorption by the gases of the earth's atmosphere. About 6,000 have been identified with the lines of known elements. Altogether about 45 elements are known to exist in the sun.

The total number of lines recorded in a flash spectrum is not so great, owing to the limitations imposed on the power of instruments which can be carried to the eclipse station, and the short duration of the eclipse. Evershed counted about 1,500 lines on his plates, Mitchell in America, using instruments of higher power during the total eclipse of 1905, increased the number to 2500.

Peculiarities of the Flash Spectrum.

From these observations, it appears that the flash spectrum is mainly a reversal of the Fraunhofer spectrum,—that is to say,—corresponding to every dark line of moderate intensity in the Fraunhofer spectrum, there is a bright line in the flash spectrum. But there are a lot of important differences. We have already alluded to the discovery of helium in the sun. A scrutiny of the Fraunhofer spectrum reveals not the slightest trace of a single helium line. On the other hand, more than 15 or 20 helium lines occur in the flash spectrum and some of them, *e.g.*, the D_3 line—rival the lines of hydrogen in brilliancy. Helium is certainly present in the sun, but why it fails at all to appear in the Fraunhofer spectrum is still wrapped up in mystery.

A similar behaviour is shown by Hydrogen. Hydrogen gives four lines in the visible spectrum, the red line $\lambda = 6563$, corresponding to the C-line of Fraunhofer; the green line $\lambda = 4861$, the F-line of Fraunhofer, the blue line $\lambda = 4340$, f of Fraunhofer, the violet line $\lambda = 4101{\cdot}8$, the h of Fraunhofer. These four lines are amongst the strongest in the Fraunhofer spectrum. About 1885, Balmer of Basle showed that the frequency 'ν' of these lines are represented with great accuracy by the simple formula

$$\nu = \frac{1}{\lambda} = N\left[\frac{1}{2^2} - \frac{1}{m^2}\right], \; m = 3, 4, 5 \text{ and } 6.$$

$m = 3$ represent the red line, $m = 5$ the green line, etc.

The extreme simplicity of the formula suggests that a deep meaning is hidden in this expression. In fact, in recent years, this formula has proved to be one of the main keys to the problem of atomic structure.

Hydrogen in the Flash.

The formula shows that the hydrogen series ought not to stop at H_δ (the 4th line of the above group), but ought to extend further in the ultraviolet, giving a large number of lines in serial order and ending at $\lambda = 3645$. The Fraunhofer spectrum shows indeed a line corresponding to $m = 7$, but most careful scrutiny fails to reveal any other lines of the series in the Fraunhofer spectrum. A number of other lines were subsequently discovered in the spectrum of the star Sirius,[1] and in the laboratory, but none in the sun.

This mystery cleared itself in the eclipse expedition of 1898. Evershed found that 29 lines corresponding to the Balmer formula are present in the flash spectrum. Mitchell later on increased the number to 35. But it is not yet clear why only 5 of them are present in the Fraunhofer spectrum.

If the reader looks carefully on the adjoining figure he will find two very big arcs, denoted by the letters H and K. They are by far the longest arcs in the flash, greatly exceeding the hydrogen arcs in length and intensity. These two arcs correspond to the H and K bands of Fraunhofer, which are the strongest absorption lines in the solar spectrum. It may be mentioned here that from the length of the arc, it is quite easy to deduce the height of the corresponding element in the solar atmosphere. The longer the arc, the greater is the height reached by the element.

These considerations show that the lines H and K occur in the highest layers of the sun. To quote exact figures, they reach the height of 14,000 km. while hydrogen reaches the height of 8,000 km. only.

The earlier astronomers, Huggins, Young and others, at first believed that the H,K lines were due to some element lighter than hydrogen, "**some subtle form of hydrogen.**" But laboratory experiments soon dispelled this illusion. It was found that the twin lines are due to Calcium !

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[1] Refer to the upper figure on page 509. The top most spectrum is that of the star Sirius. More than eight lines of hydrogen are shown.

Here is a strange enigma, a perfect riddle to astronomers. If we suppose that gravitation is the only force in the sun, it ought to act 40 times more strongly on a calcium atom than on an H-atom. Hydrogen would reach the highest levels, and then would come the other elements in order of their atomic weight.

Levity of Calcium in the Solar Atmosphere.

But this expectation is apparently most flagrantly violated in the atmosphere of the sun. Then again gravitation is 28 times stronger on the surface of the sun, hence it ought to have practically no atmosphere. A closer scrutiny brings out many other flagrant discrepancies from the physical laws as known on the earth.

Quite a crop of theories were introduced to explain these facts. Many astronomers were of opinion that there is a **force of 'levity'** in the sun, which largely neutralises the pull due to gravity. This force of levity is sometimes supposed to be due to electrical forces, sometimes to the pressure of light; sometimes to the action of convection currents. But no attempt was ever made to explain why the force of levity should act on calcium alone (and a number of other elements).

Mention ought to be made here of an ingenious theory of Prof. Julius which tries to explain away the whole set of eclipse phenomena—the chromosphere, the flash spectrum, the corona—as mere "optical illusions." The theory explains some of the general features quite well, but breaks down entirely in the treatment of details.

The first step in the elucidation of these problems was taken by Lockyer. He showed that he spectra of an element varies with the stimulus sent through the element. One set of lines come out distinctly under low stimulus (such as the flame and the arc). But if the stimulus be gradually increased these set do not so much gain in intensity; but another set begins to appear, and rapidly gains in intensity. A stage can be reached when the first set is entirely suppressed, and the second set alone remains.

The first set of lines (low stimulus lines) is generally known as arc lines; to the second set (high stimulus lines) Lockyer gave the name 'enhanced lines,' or 'spark lines.'

Lockyer discovered the remarkable fact that the high level chromospheric lines are invariably 'enhanced lines of elements' *viz.*, of Ca, Sr, Ti, Fe, Mn and Sc. The low stimulus group always occur at a lower level. To take one example, the H and K are the enhanced lines of Calcium. The line which is strongest at low temperature ('*g*' of Fraunhofer, λ = 4227) is represented by a rather short arc in the chromosphere, corresponding to a level of 4,000-5,000 kilometres. Similar behaviour is shown by the lines of other elements which are strongly represented in the solar spectrum. Their low stimulus lines fail to reach any great heights; the enhanced lines, on the contrary, reach very high levels in the solar atmosphere. From these evidences, Lockyer drew the conclusion that the chromosphere is the seat of much higher stimulus than the photosphere.

Further development of Lockyer's idea cannot be followed without a brief digression on the spectra of stars. With the aid of naked eye, it is possible to distinguish 4 classes of stars, white, yellow, yellow-red, deep-red. These stars are in the order of descending temperature, deep-red stars have the lowest temperature, white stars have the highest temperature. Secchi showed that the spectra of stars corroborate the classification based on visual observations. The spectra of the star of a particular colour is almost typical of that class.

Lockyer's studies on stellar spectra.

Lockyer worked out the transition stages very fully, and showed that the spectra of red and yellow-red stars are practically made up of low stimulus lines. The enhanced lines are only faintly present. But in the spectra of higher classes, the low stimulus lines become fainter, while the enhanced lines begin to gain in intensity. The high temperature stars practically show only 'enhanced lines.'

These facts led Lockyer to a number of hypotheses. He assumed that the spark was equivalent to a high temperature. Led by the belief that white stars represent an earlier stage in the process of evolution, he thought that elements were present there in a more primitive **(or proto)** condition. The enhanced lines are due to the "**protoforms** of the elements." Thus the '*g*' line is due to ordinary calcium, while the 'H' and 'K' are due to '**Proto calcium.**'

But the very idea that the atom, the indivisible unit of matter can be in any way further subdivided was regarded as a sort of 'heresy' in those days. In astronomical circles, the distrust with which Lockyer's views were regarded was enhanced by his attempted explanation of the spectra of the solar atmosphere. As we remarked before, the spectrum of the high level chromosphere is practically made up of "enhanced lines"; in other words, the spectrum is the same as that of a star of higher surface temperature. Lockyer therefore believed that the temperature of the chromosphere was higher than that of the disc. In other words, the temperature increases as we go outwards in the sun.

This is a rather startling conclusion and common sense never allows us to accept such a hypothesis. In the earth, to take a concrete example, the surface temperature is something like 300° (Kelvin or Absolute scale), but this decreases at the rate of 5° per kilometre as we go higher up in the atmosphere. This decrease continues for 10 to 12 kms. the temperature falls about 240°K and then it reaches an almost steady value; the temperature being maintained by exchange of radiant energy. There are very good reasons to believe that the same state of affairs holds also in the sun. The surface temperature has been determined to be about 7000° K. This decreases at a very rapid rate, but assumes a rather steady value of 5500° K at the higher levels. This view is apparently inconsistent with Lockyer's idea. Still, the fact that the chromosphere is the seat of higher stimulus has to be explained.

A theory to explain these facts was given by the present writer about a year and a half ago, which has met with general acceptance. But an account of this theory will be out of place here.

The coronal spectrum. The spectrum of the corona is one of the most puzzling riddles of solar physics. The spectrum shows a number of lines which are not coincident with any Fraunhofer or flash line, or with the line of any known element. The best known line is $\lambda=5303$, which was in early times confused with a line of iron having the wave length of $\lambda=5316$. This line and its associate lines are ascribed to a hypothetical element called "**coronium.**" But "coronium" has not yet made its appearance on the earth.

In the light of modern theories of atomic structure, it does not seem probable that "coronium" will turn out to be a newcomer in Mendelieff's family of elements, but will prove to be, like Lockyer's Protocalcium or Protovanadium, only a modified form of some known element.

The Coming Total Solar Eclipse.

It will be seen that beginning with the memorable eclipse of 1868, most of the important eclipse observations were made in India. The eclipse of Sept. 21, 1922, will however pass south of India. The adjoining fig. shows the track of the eclipse. Beginning from the east coast of Africa, it will sweep across the Indian Ocean. The original plan was to have three eclipse stations, one at the Maldive Islands, the second at the Christmas Islands, south of Java, the last on the west coast of Australia. The Maldive project has subsequently been given up. A British party and a joint Dutch and German party will camp at the Christmas Islands. Here the duration will be 3m 40s but the station is not exactly at the centre of the moon's shadow, but fifty miles south of it. The sun will be nearly at the zenith, and there are good prospects of fair weather. The British party is composed of Mr. Spencer Jones, M. Melotte and observers from the Greenwich observatory, while the Dutch party will be under the leadership of J. G. Voute, Director of Meteorological Survey in the Dutch Indies. Germany will be represented by Freundlich, Kohlschütteer, and probably Einstein.

In Australia, probably both the west and east coasts will be occupied, by an American party under Prof. Campbell of the Lick Observatory, and an English party in which Australia will be represented. Mr. Evershed from India will probably encamp somewhere in the west coast of Australia. Here the duration will be 5^m 18^s and the sun will be nearly 60° high. The weather prospects are said to be favourable.

A question which is asked in this country—what is the good of all this fuss—may be answered here. The sun is the source of all life on this earth. It controls the weather, the winds, the rainfall, the currents in the ocean. All sources of power and energy are to be traced ultimately to the sun. If the physics of the sun were accurately known, it is only a question of time that meteorological problems, vital to mankind would find their complete solution. Wind, rainfall, changes of weather would be then calculated in advance like the motion of planets. It seems that the attainments of this goal is only a question of time. The journey is long, the goal is not yet in sight, but if the scientific activity of mankind be allowed to continue, probably some day it will be reached.

MEGHNAD SAHA

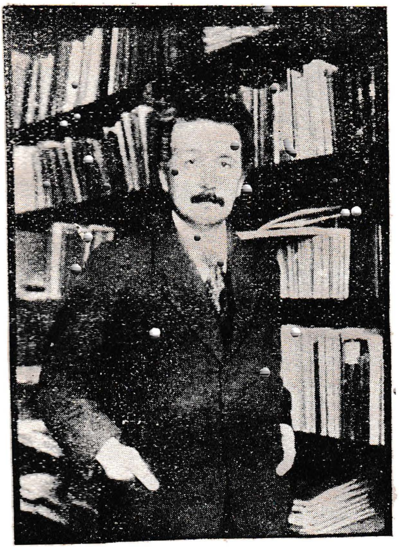


Fig. 1

Prof. Albrecht Einstein.

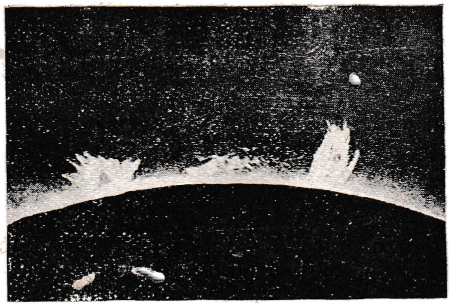


Fig. 2

A typical Solar Prominence photographed during the total solar eclipse on May 29, 1900 (from Hale's Stellar Evolution).

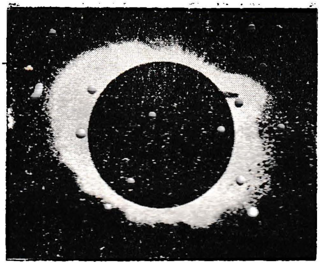


Fig. 3

The lower figure represents a photograph of the Solar Corona (from Hale's Stellar Evolution).

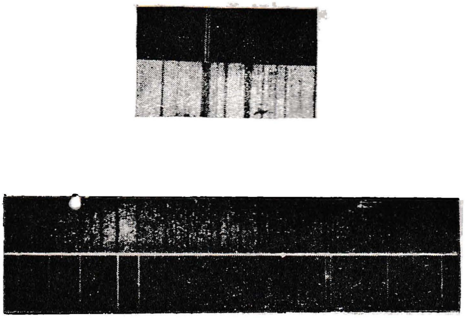


Fig. 4

The upper figure shows the sodium lines in arc, and in the sun.
The lower figure shows the coincidence of iron lines in the arc with those in the Sun (Hale, Stellar Evolution).

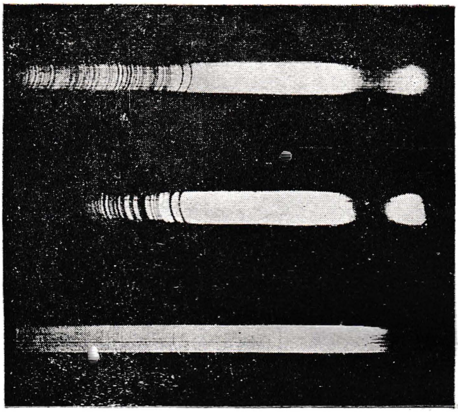


Fig 7

(From an article in the Phil. Trans., Vol. 197, by Evershed.)

The uppermost figure is the spectrum of the thin solar cusp just before totality. The middle one represents the spectrum of an artificial cusp on an ordinary day.

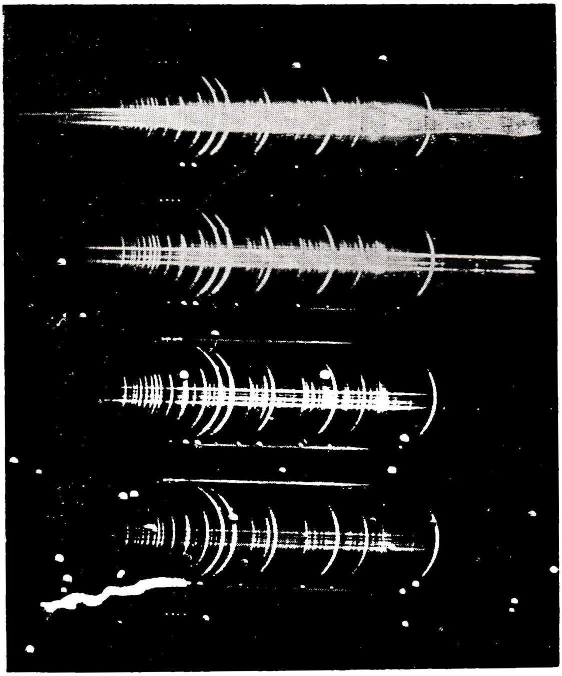


Fig. 8

Flash Spectrum.

(From an article by Lockyer in the Phil. Trans., Vol. 197.)

The longest arcs are due to calcium lines H and K. The shorter arcs to the left H and K are the ultra-violet lines of hydrogen. They are not present in the Fraunhofer spectrum.

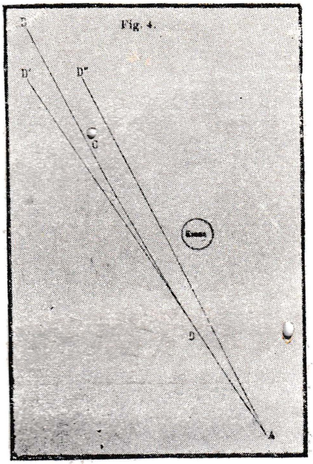


Fig. 5

(From Laue's Relativitätsprinzip.) Diagram showing the deflection of light-rays. The star at D is shifted to D''. (1) represents the sun.

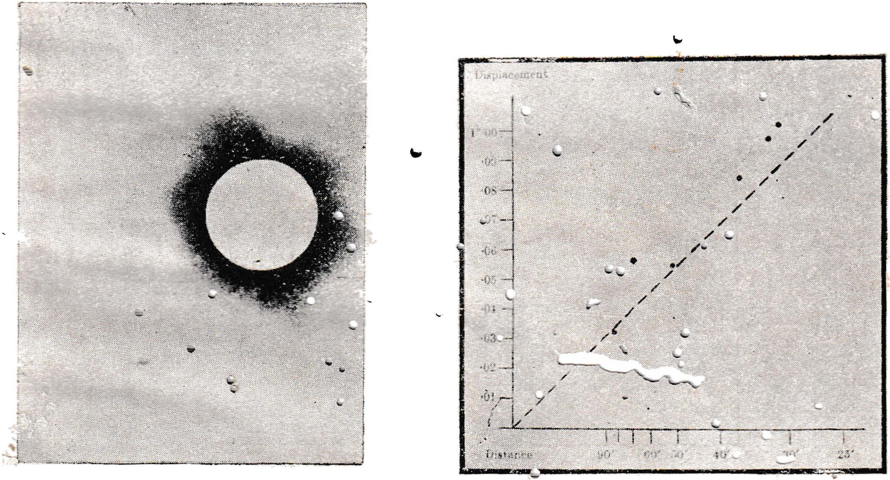


Fig. 6

(From Laue's Relativitätsprinzip.) Photograph of the field of stars about the sun, secured by the British Expedition at Sobral. The corona is also shown. The second figure shows the result diagrammatically.

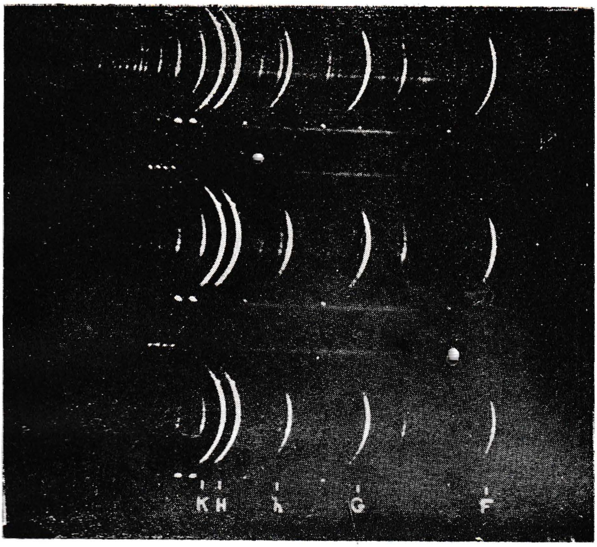


Fig. 9

Photograph of the Flash Spectrum secured on Jan. 22, 1898, at Viziadrug in the Bombay Presidency by the Lockyer Expedition (from Phil. Trans., Vol. 197). The H-K arcs are due to radiant calcium, **F. G. h.** are due to radiant hydrogen.

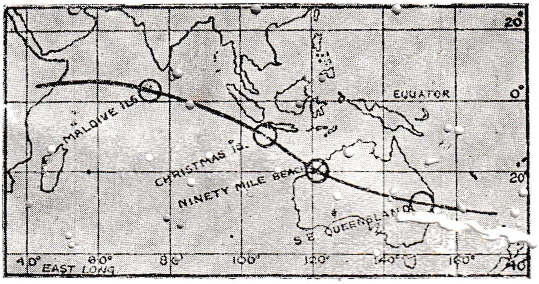
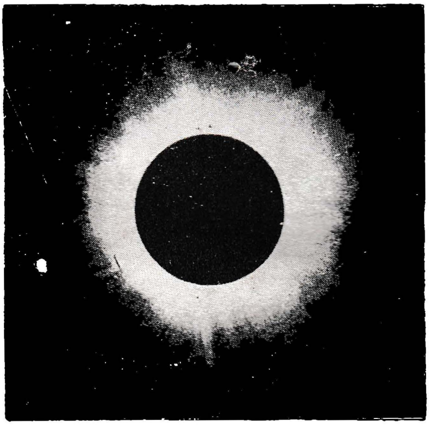


Fig. 10

(From an article in the Nature, Dec. 29, 1921, by Dr. W. J. S. Lockyer.)

Track of the moon's shadow during the coming total solar eclipse, Sept. 21, 1922. The small circles denote the site of the eclipse stations. The Maldive project has been given up.



Photograph of Solar Corona secured during
the total solar eclipse of 1870.
(From Pringsheim's Physik der Sonne.)

Sir Norman Lockyer.
(1838-1920)
From an obituary notice in the Astrophysical
Journal, Vol. 50, 1921.